Table 4.4 Average Slope of Water-surface Profiles for High- and Low-flow Conditions in Selected River Reaches for Individual Years Between 1967 and 1974 and Average Slope for Each Flow Condition for the Period.

		1967	1968	1969	1970	1971	1972	1973	1974	AVE
Mississippi River from Alton, Illinois to Birds Point, Missouri	High	.574	.559	.582	.604	.519	.531	.588	.566	.565
	Low	.571	.471	.552	.555	.557	.530	.507	.589	.542
From Hermann on the Missouri River to St. Louis on the Mississippi River	High	.880	.878	.811	.830	.851	.866	.781	.810	.838
	Low	.948	.934	.941	.938	.929	.923	.928	.941	.935
Mississippi River from Hannibal, Missouri to Alton, Illinois	High	.317	.456	.402	.415	.473	.467	.402	.432	.421
Mississippi River from Keokuk, Iowa to Alton, Illinois	High	.426	.451	.413	.419	.470	.470	.415	N.A.	.438
From Meredosia on the Illinois River to Alton on the Mississippi River	High	.087	.216	.109	.204	.192	.198	.142	.178	.166

Mississippi Reach (Alton to Birds Point), whereas the situation is reversed in the Missouri River Reach because the St. Louis gage is below the mouth of the Missouri River and the Chain of Rocks topographic control.

The primary function of dikes has been stabilization of the navigation channel. To a lesser extent, they have been used to initiate chute closures and to create storage space for dredging spoils. The earliest record of dike construction in the Mississippi River between Alton, Illinois and Head of Passes, Louisiana is in 1834 when dikes were constructed near river mile 194 above Cairo, Illinois. Most dike construction has occurred between the mouth of the Missouri River and Cairo (St. Louis Reach), a distance of about 195 river miles. Between 1870 and 1900, dike construction in the St. Louis Reach amounted to about 300 dikes with a cumulative length of about 285,000 feet. During this period, most construction took place upstream from Crystal City, Missouri (river mile 149) and tended to concentrate opposite settlements. About 27,000 feet of the total for this period were built upstream from the present Market Street gage (mile 179.7) to keep the river next to St. Louis harbor facilities.

Between 1900 and 1924 only about 60,000 feet of dikes were added to the St. Louis Reach. As shown in Figure 4.12, accelerated construction activity began about 1925 and continued through 1940. During that period, about 469,000 feet were built to bring the cumulative length to about 766,000 feet. From 1940 to 1955, construction activity decreased markedly. Only 85,000 feet were added during this period. Rate of construction increased again between 1955 and 1970. Beginning in 1970, construction of new dikes decreased by more than an order of magnitude from

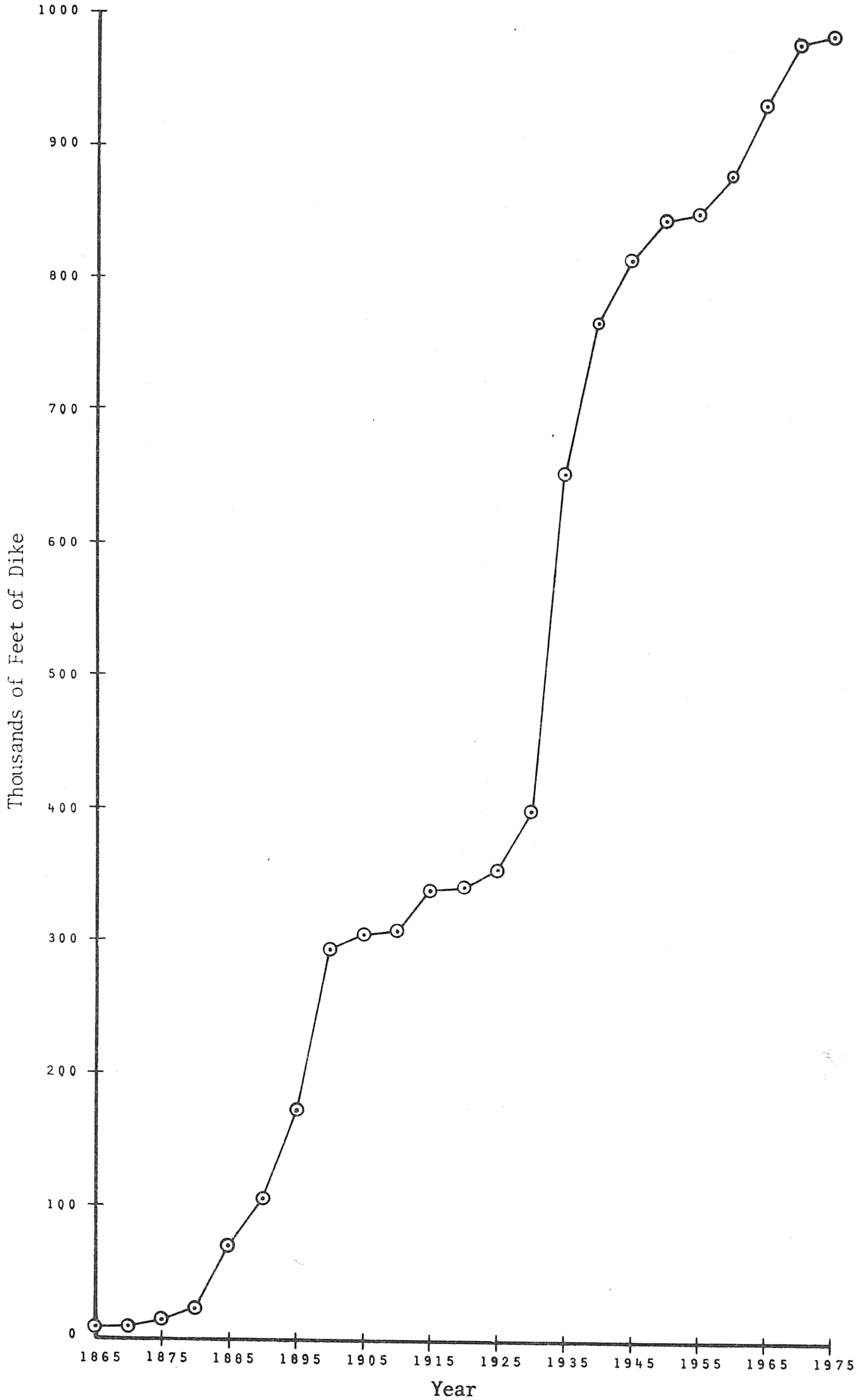

Figure 4.12. Cumulative Length of Dikes Constructed in St. Louis Reach, 1865-1975

the previous 5-year period. By 1975, about 1100 dikes with a cumulative length of 982,000 feet had been built in the St. Louis Reach.

Figure 4.13a shows the average top-bank widths of the St. Louis Reach as scaled from hydrographic surveys and aerial photographs at intervals of about 2 miles for selected years between 1908 and 1974. Top-bank width was taken as the distance between first vegetation. The average width decreased from about 3320 feet in 1908 to about 2370 feet in 1974, a decrease of about 29 percent. However, it should not be inferred from Figure 4.13a that the rate of decrease was necessarily uniform. There are insufficient determinations to describe the time distribution of change. It is clear that river width in this reach has decreased in response to dike construction activity.

As shown in Figure 4.14 for the reach between the White River and Cairo, Illinois (Memphis Reach; river mile 596 to 954 above Head of Passes), although dike construction was initiated in 1900 there was relatively little construction activity until 1956. In 1955 there were about 11,000 feet of dikes. Between 1956 and 1974, approximately 222 dikes with a cumulative total length of 505,000 feet were added. Figure 4.13b shows average top-bank width of the Memphis Reach for selected years. Unlike the St. Louis Reach, there is no obvious relationship between average top-bank width and dike construction for the Memphis Reach.

In the reach between Old River Structure and the White River (Vicksburg Reach; river mile 321 to 596), records show a construction date for only one dike prior to 1962. Hydrographic surveys show a limited number of dikes prior to 1962 but construction dates are not indicated. Between 1962 and 1974, there were 123 dikes built with a cumulative

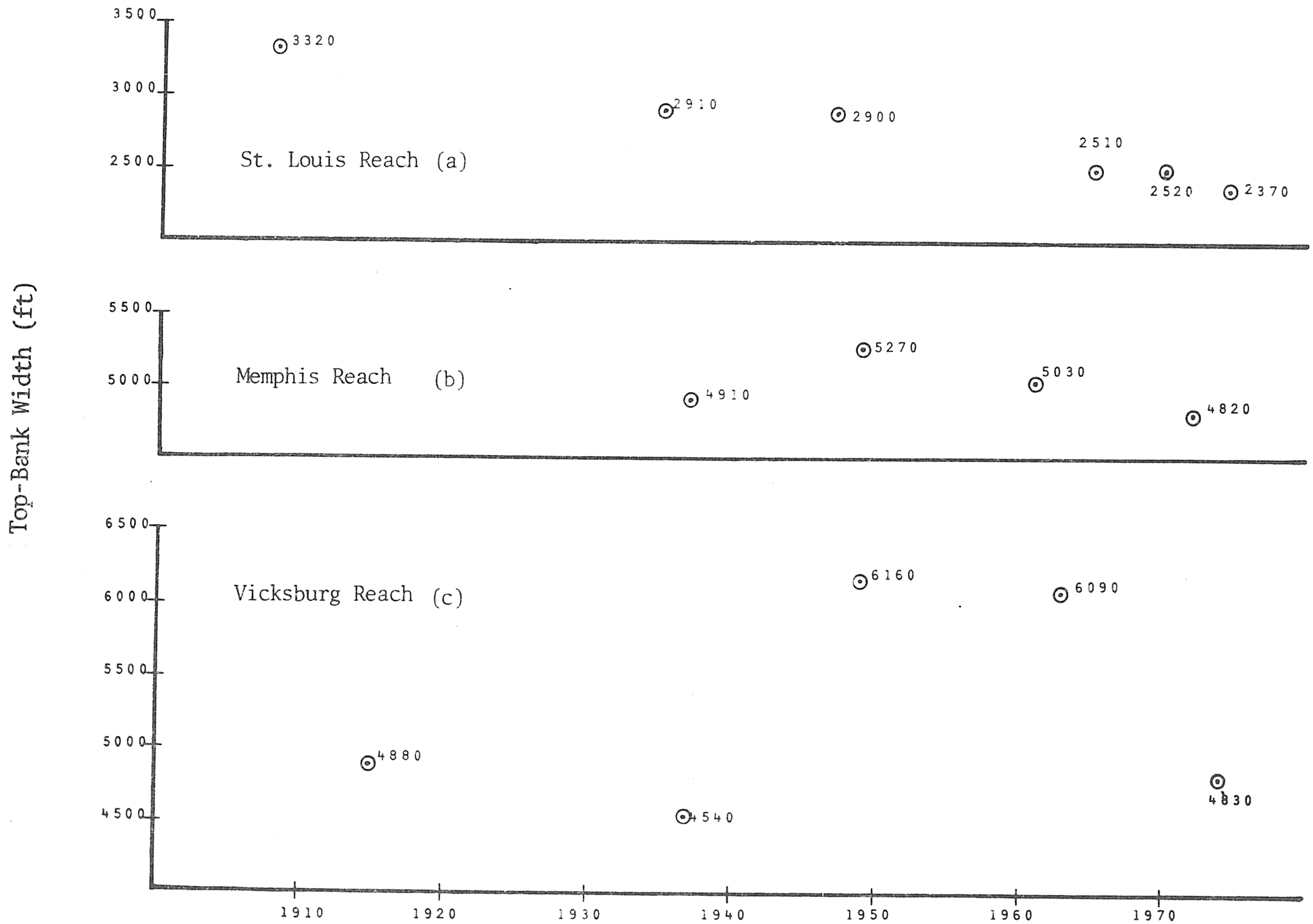

Figure 4.13 - Average Top-Bank Widths of the Mississippi River

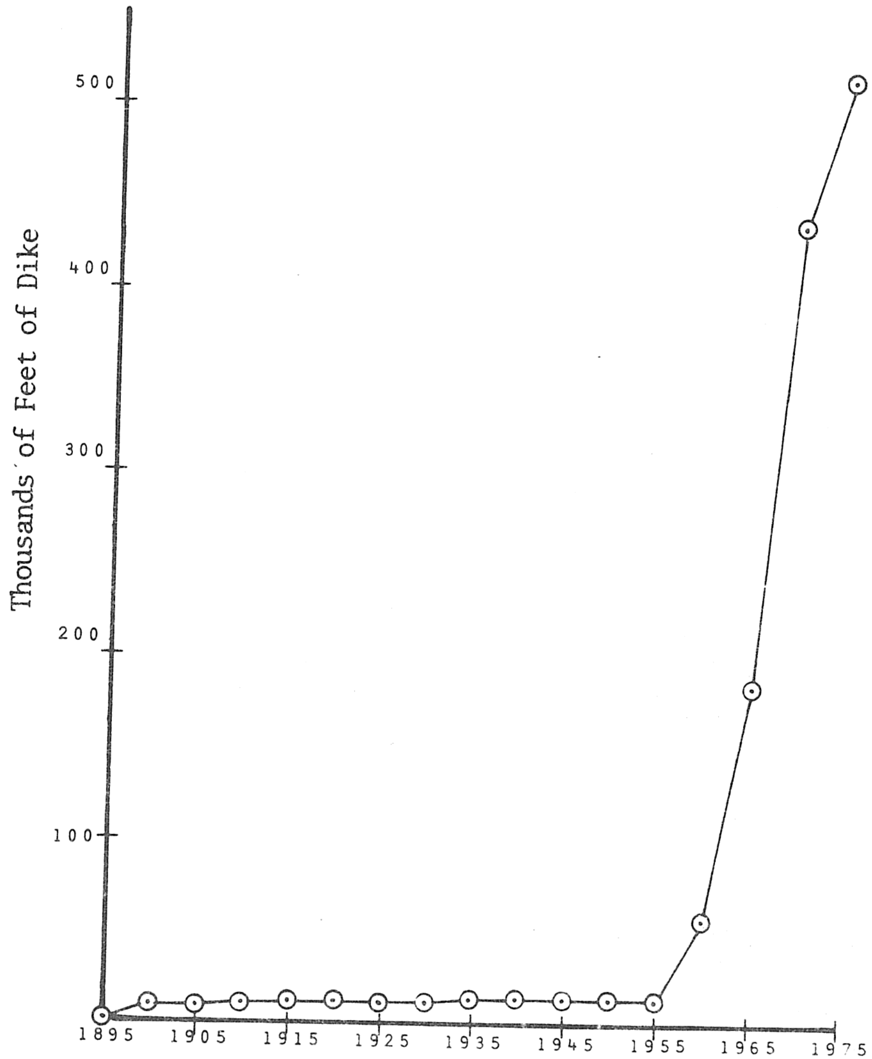

Figure 4.14 - Cumulative Length of Dikes Constructed in the Memphis Reach, 1900-1975

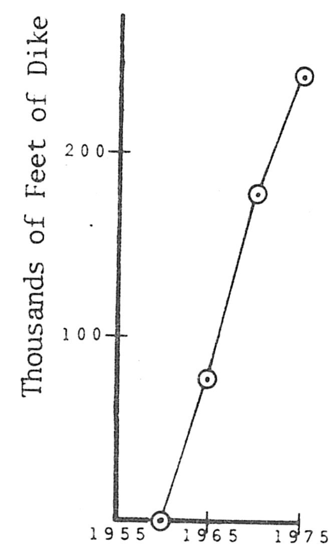

Figure 4.15 - Cumlative Length of Dikes Constructed in the Vicksburg Reach, 1955-1975

length of about 243,000 feet. Figure 4.15 shows the cumulative length of dikes constructed in this reach between 1955 and 1975. Figure 4.13c shows average top-bank widths for Vicksburg Reach for selected years. The decrease between 1963 and 1974 is nearly as large as the increase between 1937 and 1959. Dike construction in the St. Louis Reach was about 5030 feet/mile, in the Memphis Reach about 1400 feet/mile, and in the Vicksburg Reach about 890 feet/mile. In the Memphis Reach, average top-bank width is about twice and dike density in terms of feet per mile is only about one-fifth that in the St. Louis Reach. Therefore, a causal relationship between dike construction and changes in top-bank width in the Memphis Reach should not be inferred without further analysis. Because cumulative length of dikes per mile in the Vicksburg Reach was less than in the Memphis Reach and large bank-width changes have been observed both prior to and after dike construction, any association between dike construction and reduction of top-bank width in the Vicksburg Reach after 1963 is probably unwarranted at this time.

Because dikes constrict the channel (at least in the vicinity of individual dikes) it was necessary to determine if there have been associated changes in stage-discharge relationships over time. The analytical procedure was the same for all stations. The mean-daily discharges were plotted against mean-daily stages for every year of continuous record. Plots were on both arithmetic and logarithmic coordinates. The "average" stage-discharge curve for each year was estimated for fitting a smooth curve to the data by eye. Because the plotted points were approximately linear on the logarithmic coordinates, an estimated straight line of best fit was used. Flow rates were selected to be representative of low, medium bankfull, and overbank conditions. These fixed flow rates were used in conjunction with the stage-discharge curves to estimate prevailing stage for each flow rate for each year. Stages were then plotted as a function of time.

There was a number of years when bankfull conditions were not realized. Stages for these years were extrapolated from the logarithmic plots for the year in question. This method nearly always resulted in reasonable values of stage for bankfull flow conditions. For flows greater than bankfull, the difference between estimated stages was often 4 feet or more for adjacent years. This was particularly evident when extrapolations were made from rating curves developed for drought years. Because of the extreme variability of above bankfull estimates and because there are relatively few observations above bankfull to use as controls, it was not possible to make an evaluation of changes in flood stages with respect to time as influenced by levee construction. Therefore, no inferences were drawn with respect to effects of levee construction on stage-discharge relationships.

The procedure outlined above was followed for the following stations:

1. Hermann on the Missouri River
2. St. Louis
3. Chester
4. Thebes
5. Metropolis on the Ohio River
6. Memphis
7. Vicksburg

Continuous records were not kept for the above stations until 1930 or later. For that reason and because flow-measuring techniques were not standardized for earlier years, the principal part of the stage-change analysis is based on the post-1930 record.

Figure 4.16 shows stage versus time for selected flows in the Missouri River at Hermann, Missouri. Flood stage at Hermann is 21 feet. Discharge at flood stage is approximately 211,800 cfs. Stages were not estimated for overbank conditions unless an observed flow was greater than 211,800 cfs. For the period, 1930 to 1974, it appears that stages have increased for all flows between 64,700 cfs and 337,000 cfs. Stage increases have ranged from about 2 feet for 64,700 cfs to about 3.5 feet for 337,000 cfs. It was not within the scope of this project to collect data which might relate to stage behavior at this station.

Figure 4.17 shows stage versus time for selected flows in the Mississippi River at St. Louis, Missouri. It is clear from the plotted data that, since 1934, stages have decreased for flows less than 280,900 cfs. With the statistic Z at the 2-percent level of significance as a test criterion, a downtrend with time was also found to exist for bank-full conditions (501,300 cfs). It appears that since 1934, stages have decreased about 1.4 feet for all flows between 501,300 cfs and 154,800 cfs.

Prior to 1934, relatively few flow measurements were made at the St. Louis gage. For those years when there were sufficient data to define a stage-discharge relationship, it was possible to estimate stages corresponding to the same flow rates which were used for the post-1934 stage-change analysis (Fig. 4.17). Those estimates are shown in the following table:

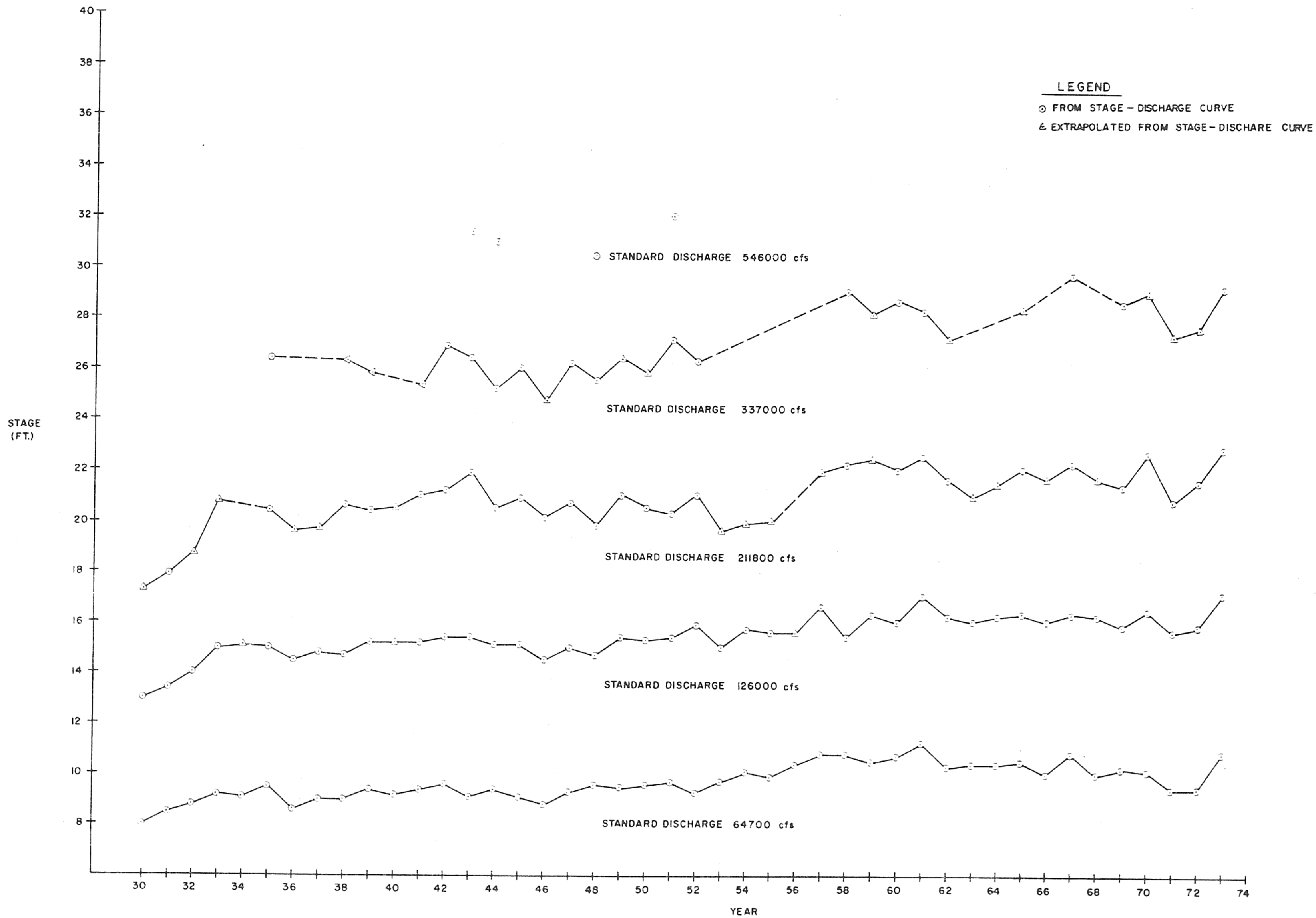

Figure 4.16 Estimated River Stage for Selected Flows in the Missouri River at Hermann Between 1930 and 1974

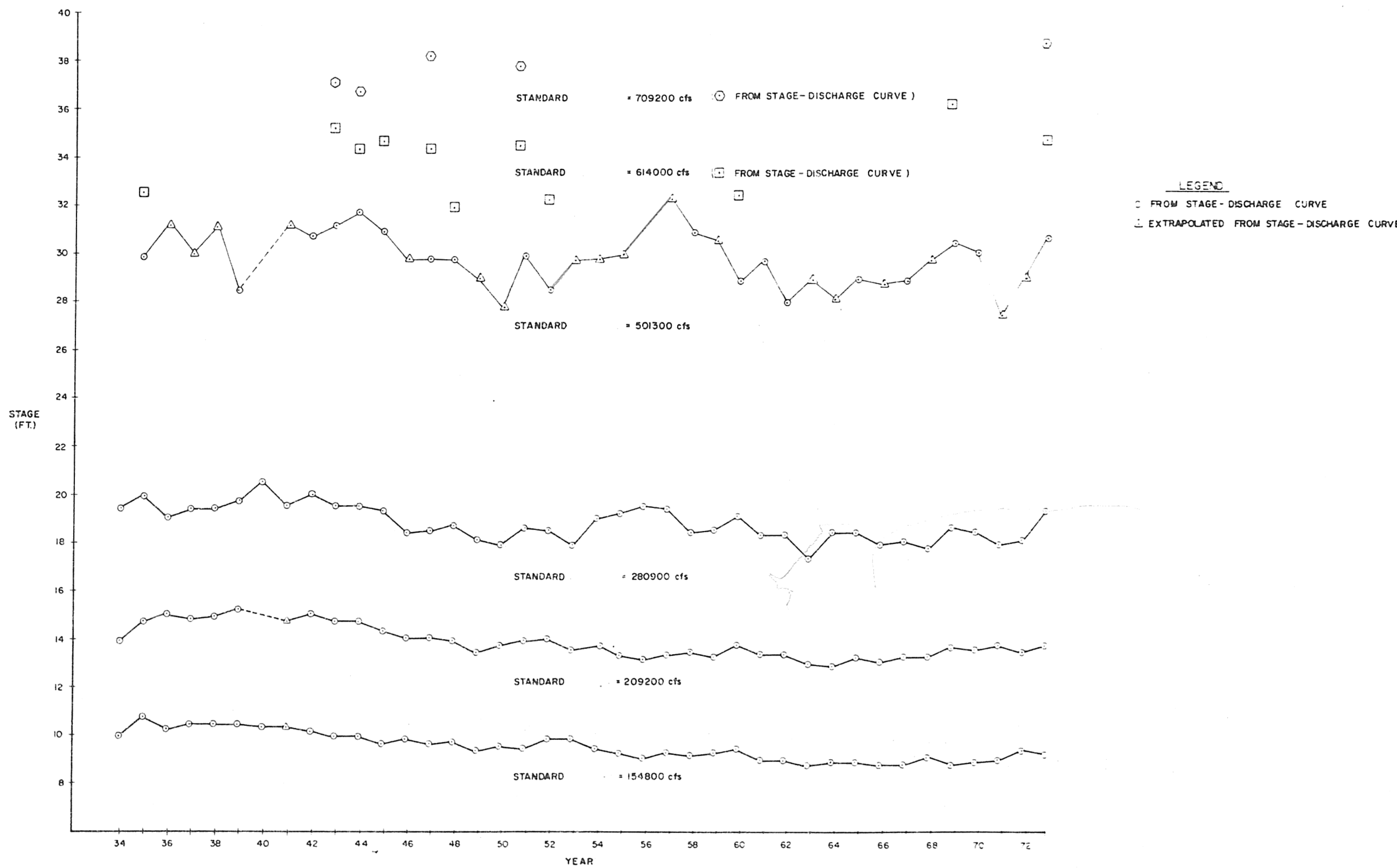

Figure 4.17 Estimated River Stage for Selected Flows in the Mississippi River at St. Louis Between 1934 and 1973

Discharge (cfs)	1881	1900	1903	1904	1934
	(Stages are in feet)				
501,300	25.2	26.5	27.8	28.5	29.9
280,900	18.0	18.7	20.0		20.0
209,200	15.1	15.4	16.0		14.8
154,800	11.5	12.5	12.2		10.8

The indication is that, for flows greater than 280,900 cfs, stages increased during the period from 1881 to 1934. During the same period, flows less than about 209,200 cfs probably passed the St. Louis gage at progressively lower stages.

Prior to about 1930, velocities were measured with a variety of equipment and in accordance with a variety of field procedures. Methods for calculating flow rates from velocity and sounding data were not standardized. Although equipment and field and calculation procedures are now standardized, the U.S. Geological Survey still occasionally describes accuracy of their published mean daily discharge figures at St. Louis as "good". This classification means that 95 percent of the mean daily flows are within 10 percent of the true value. If pre-1934 flows were determined according to contemporary techniques, they would probably differ from those shown in the preceding table. It seems reasonable to expect that the difference could be 20 percent or more.

If flows measured prior to 1934 are in error, then stages which correspond to flows shown in the preceding table are in error. As discussed previously, plots of mean daily stage versus mean daily discharge for each year after 1934 were nearly linear on logarithmic coordinates. A straight line fitted to these data implies an approximate exponential relationship between stage and flow of the form

$$S = MQ^n$$

where S = stage,

Q = flow rate,

n = slope of the straight line fitted to a plot of the logarithm of stage versus the logarithm of discharge, and

M = a constant (the stage which prevails when the flow rate is unity).

If the exponential relationship between stage and discharge is assumed to be a valid approximation, the stage-estimate error resulting from a flow measurement error can be expressed as

$$E_s = \{(\frac{Q_m}{Q_t})^n - 1\} \times 100$$

where E_s = percent error in stage estimate,

Q_m = measured flow rate,

Q_t = true flow rate, and

n = exponent as determined from the stage-discharge relationship.

Exponents (n) for the post-1934 years range from 0.42 to 0.51. If the same general stage-discharge relation is assumed to hold for the pre-1934 period and if the flow measurement error is taken to be 20 percent (Q_m/Q_t = 0.8 or 1.2), then the percent error in stage estimate (E_s) can be shown to be approximately ±10 percent. Therefore, if flow measurements prior to 1934 were systematically 20 percent too high, estimated stages shown in the previous table should be increased by about 10 percent, whereas the converse is true if measured flows were less than the true flows. The following tables show stage-change trends as they might appear if the pre-1934 measurements were 20 percent too high and 20 percent too low, respectively.

For $Q_m/Q_t = 1.2$ (Measured flows greater than the true value):

Discharge (cfs)	1881	1900	1903	1904	1934
		(Stages are in feet)			
501,300	27.7	29.2	30.6	31.4	29.9
280,900	19.8	20.6	22.0		20.0
209,200	16.6	16.9	17.6		14.8
154,800	12.7	13.8	13.4		10.8

For $Q_m/Q_t = 0.8$ (Measured flows less than the true value):

Discharge (cfs)	1881	1900	1903	1904	1934
		(Stages are in feet)			
501,300	22.7	23.8	25.0	25.6	29.9
280,900	16.2	16.9	18.0		20.0
209,200	13.6	13.9	14.4		14.8
154,800	10.3	11.2	11.0		10.8

Figures in the two preceding tables demonstrate that differences between early and contemporary flow determinations (if they exist) would lead to conclusions about direction and rate of change of stage between 1881 and 1934 which are different from those indicated by the existing record. Therefore, unqualified acceptance of pre-1934 stage-change behavior is not justifiable without corroborating evidence that early and contemporary flow determinations are reasonably comparable.

Figure 4.18 shows stage versus time for selected flows in the Mississippi River at Chester, Illinois. Flood stage at Chester is 27.0 feet which corresponds to a flow of about 440,000 cfs. With the statistic Z at the 20-percent level of significance as a test criterion, there

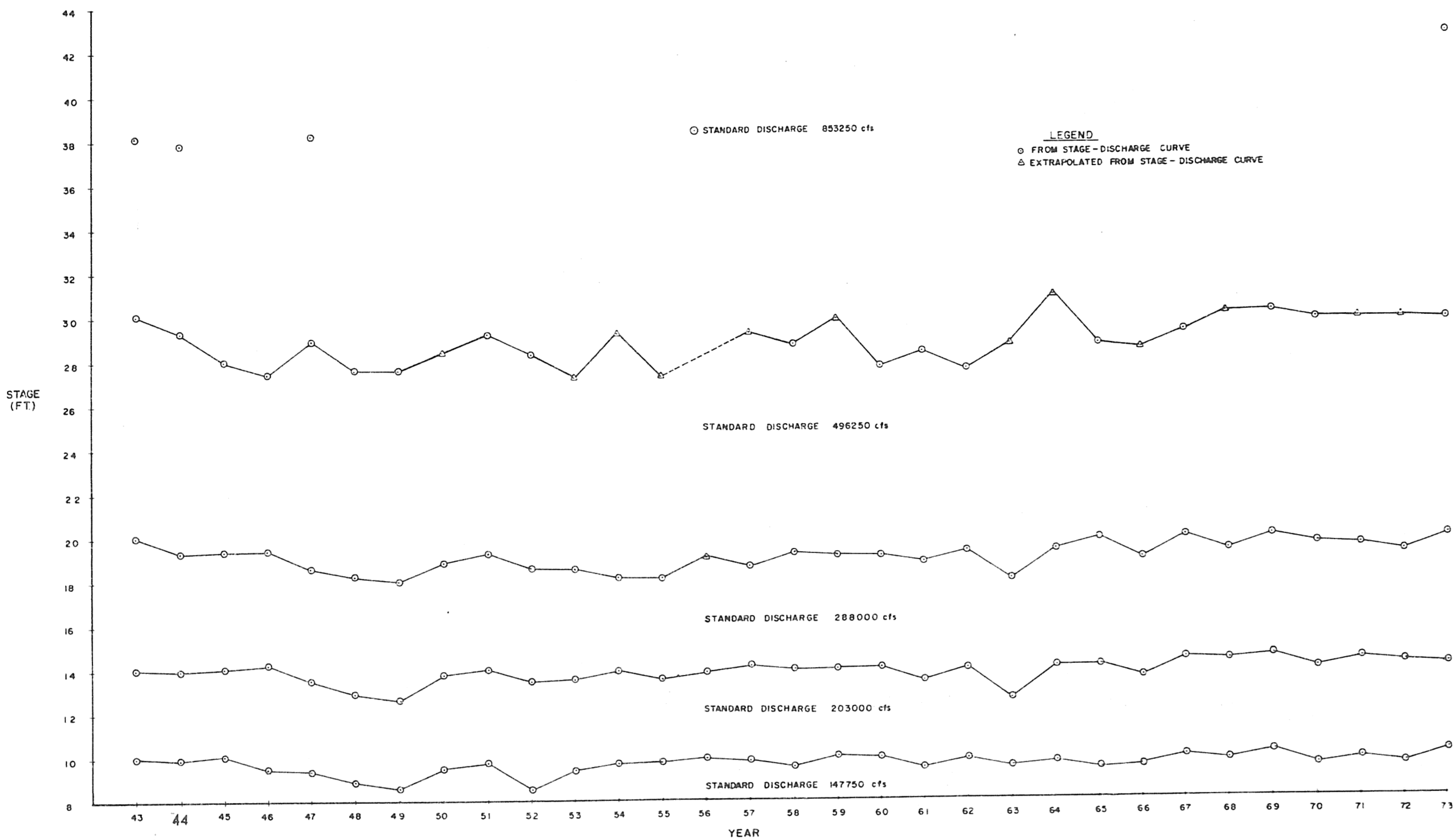

Figure 4-18 Estimated River Stage for Selected Flows in the Mississippi River at Chester Between 1943 and 1973

were no discernible trends in stages for flows less than 496,250 cfs for the period, 1943 through 1973.

Figure 4.19 shows stage versus time for selected flows representing low, mid-range, and bankfull conditions in the Mississippi River at Thebes, Illinois. Stages for low flows appear to have decreased between 1934 and 1973. For instance, with the statistic Z at the 1-percent level of significance as a test criterion, stages for flows between 87,000 cfs and 135,000 cfs decreased about 3 feet and 3.5 feet, respectively, between 1934 and 1973. However, stages for mid-range flows (about 219,000 cfs) remained practically unchanged over the same period.

Flood stage at Thebes is about 33.0 feet. In 1941 a stage of 33.0 feet corresponded to a flow of nearly 572,000 cfs,whereas by 1973 the same stage corresponded to a stage of about 481,000 cfs. Although it appears that the bankfull capacity has decreased since 1934, the decline has not been continuous. From 1934 to about 1963, stages for flows between 481,000 cfs and 572,000 cfs remained essentially unchanged. Because stages for mid-range flows also remained nearly constant, it may be inferred that stages for all intervening flows from about 219,000 cfs to about 572,000 cfs remained relatively stable over the period. However, between 1963 and 1973, stages for the approximate bankfull condition (481,000 cfs to 572,000 cfs) increased steadily to about 2.5 feet over the 1962 condition. Therefore, it appears that for the post-1963 period, stages for mid-range flows remained constant while stages increased for those higher flows near the bankfull condition.

Because of backwater effect from the Ohio River it is common to find 2 feet or more variation in stage at Thebes for discharges greater

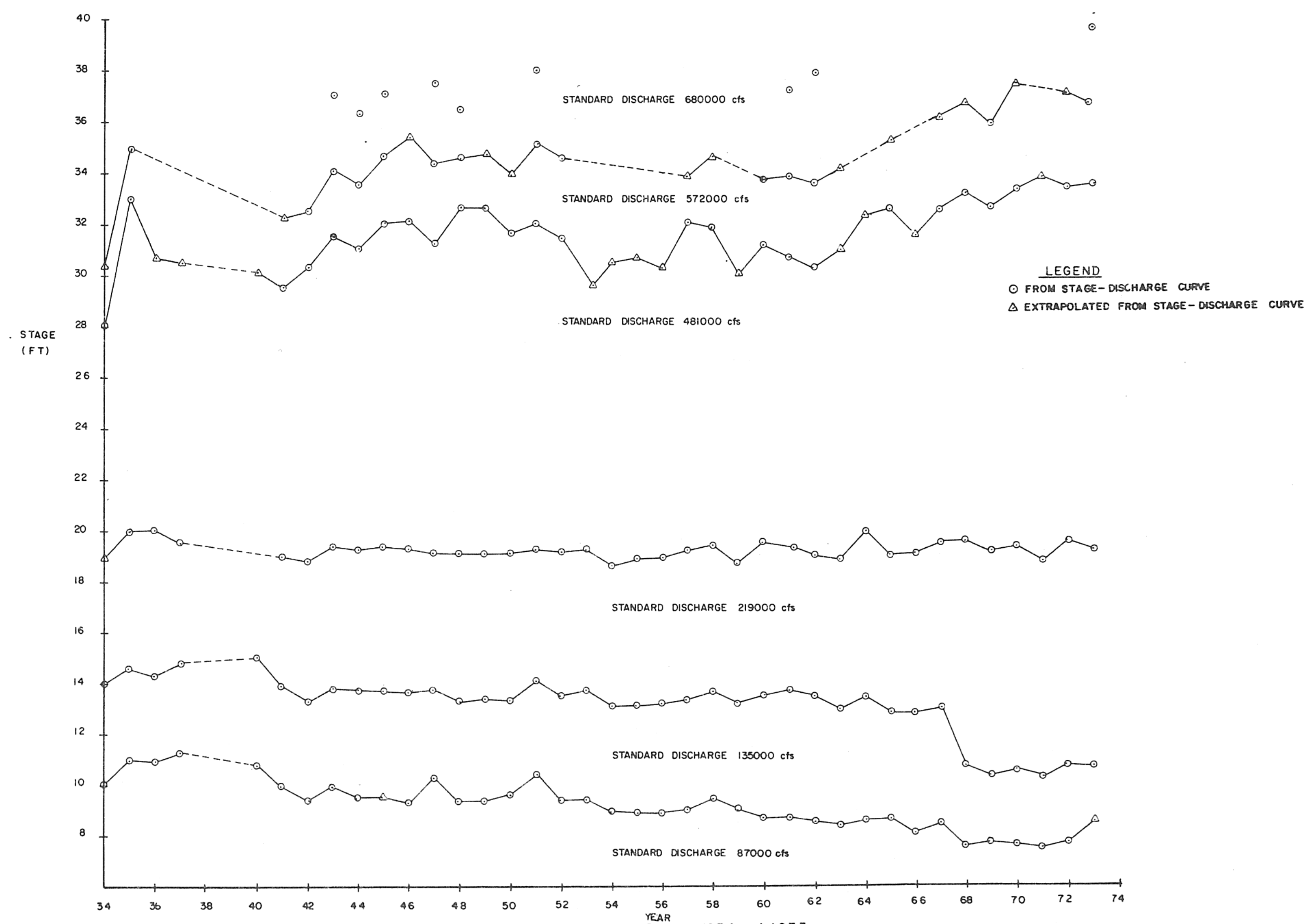

Figure 4.19 Estimated River Stage for Selected Flows in the Mississippi River at Thebes Between 1934 and 1973

than 431,000 cfs. For this reason, and because pertinent flow data for the period prior to 1934 are few, existing stage-discharge data are insufficient for a comparison of pre-1934 and post-1934 stages for flows considered herein.

Figure 4.20 shows stage versus time for selected flows of the Ohio River near Metropolis, Illinois. Flood stage is 43 feet. The pattern is very similar to that of the Mississippi River at Thebes. As at Thebes, stages for low flows (66,600 cfs) have decreased and stages for flows about midway between bankfull and low flows have remained about the same for the period, 1936 through 1973. However, stages for flows near bankfull (774,000 cfs) appear to have increased nearly uniformly since 1936, whereas the corresponding increase at Thebes began about 1963.

Because mean annual flow from the Ohio River is about 46 percent greater than that in the Mississippi River at Thebes, it is possible that those factors which cause changes in the stage-discharge relation in the Ohio River near its confluence with the Mississippi River also will be reflected by similar changes in the stage-discharge relation at Thebes. This speculation is based on similarities in stage-behavior patterns between Metropolis and Thebes. In order to assess the validity of such a possibility, it would be necessary 1) to determine which factors are associated with the stage-behavior pattern at Metropolis, 2) to determine if the observed patterns are representative of the intervening reaches between Metropolis and Thebes and the confluence of the Ohio and Mississippi Rivers, and 3) to analyze the relative time distribution of flow and sediment load from the Mississippi and Ohio Rivers past their confluence.

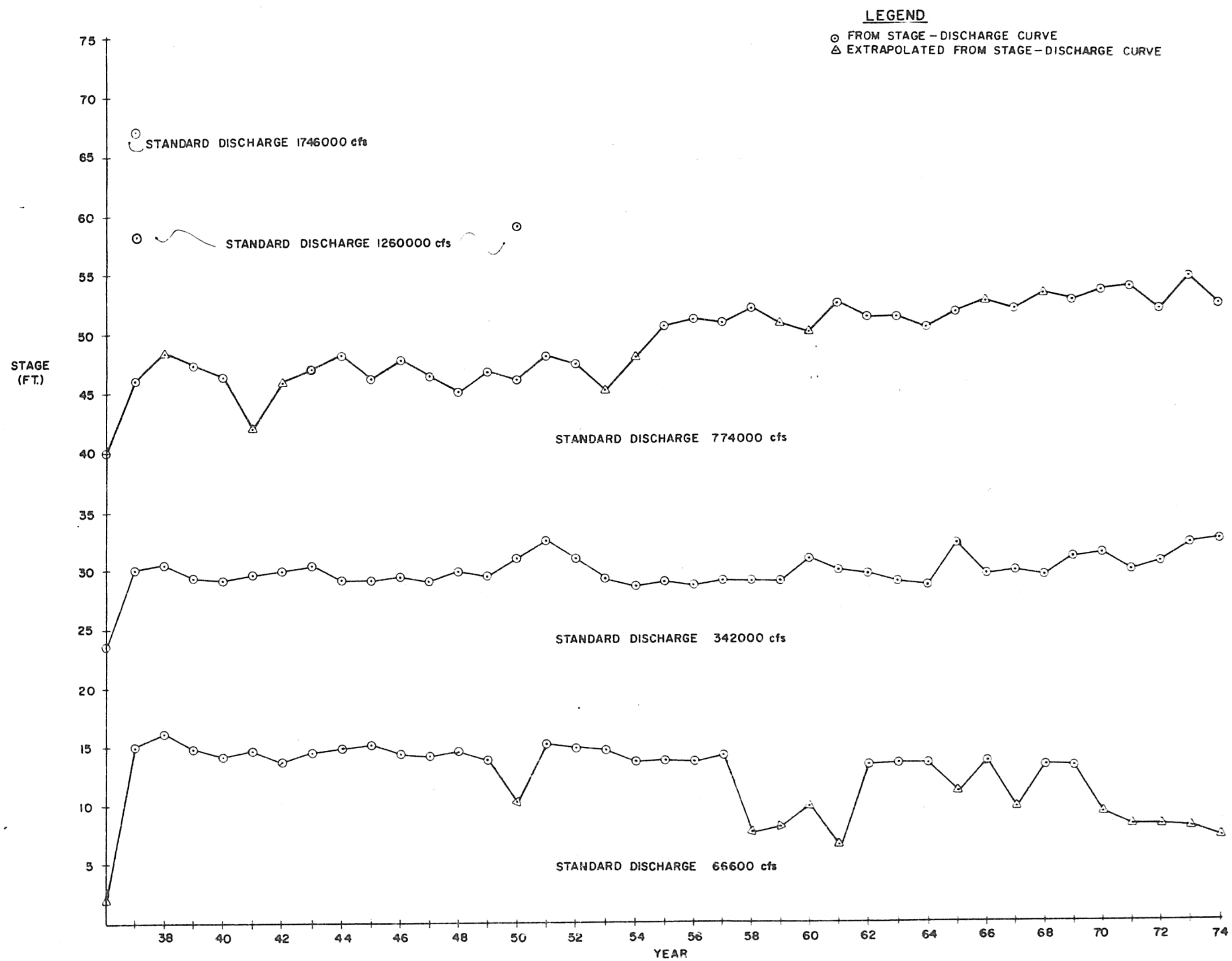

Figure 4.20 Estimated River Stage for Selected Flows in the Ohio River at Metropolis Between 1936 and 1974

Figure 4.21 shows stages versus time for selected flows in the Mississippi River near Memphis, Tennessee during the period, 1933 through 1971. Flood stage at Memphis is 34 feet. Stages for all flows below bankfull have continuously declined since 1933. Stage declines for the period, 1933 through 1971, range from about 3 feet for flows of 1,070,000 cfs to about 6 feet for flows of 260,000 cfs. Records show that in 1890 a flow of 1,070,000 cfs passed Memphis with a stage of 31.5 feet. For that flow rate the 1890 stage was greater than the 1933 stage, but it was less than the 1971 stage. Therefore, it appears that even though there was a decrease in channel capacity, it was temporary. Higher flow rates could be sustained within banks at the Memphis gage in 1971 than could be sustained in 1890.

Figure 4.22 shows stages versus time for selected flows in the Mississippi River near Vicksburg, Mississippi. Flood stage at Vicksburg is 43 feet. All stages for flows near bankfull and below have a similar behavior pattern. In the period, 1931 to about 1942, stages for flows of 1,340,000 cfs or less declined approximately 10 feet. Prior to 1931, stages for 1,340,000 cfs range from estimated extremes of 52 feet in 1858 to 46.9 feet in 1909. In 1913, the stage for 1,340,000 cfs was slightly greater than 48 feet, whereas in 1927 and 1929 it varied between 49 feet and 52 feet. Apparently, whatever factors may have caused the downtrend in stages between 1931 and 1942 manifested themselves after 1931. Beginning in 1942, there was a trend reversal showing steady increase in stages. By 1972 stages for flows near bankfull and below had recovered between 4 feet and 5 feet from the 1942 condition.

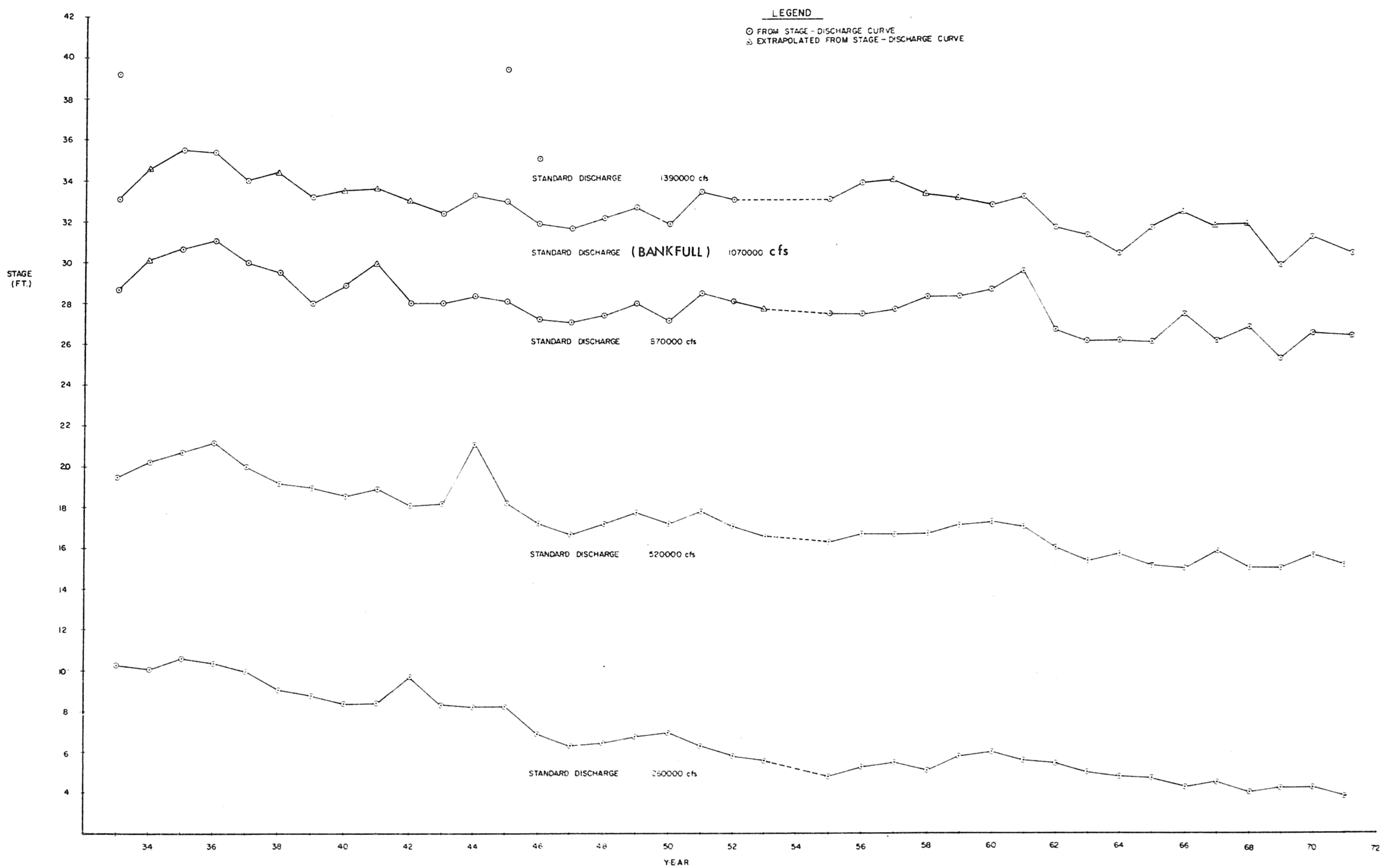

Figure 4.21 Estimated River Stage for Selected Flows in the Mississippi River at Memphis Between 1933 and 1971

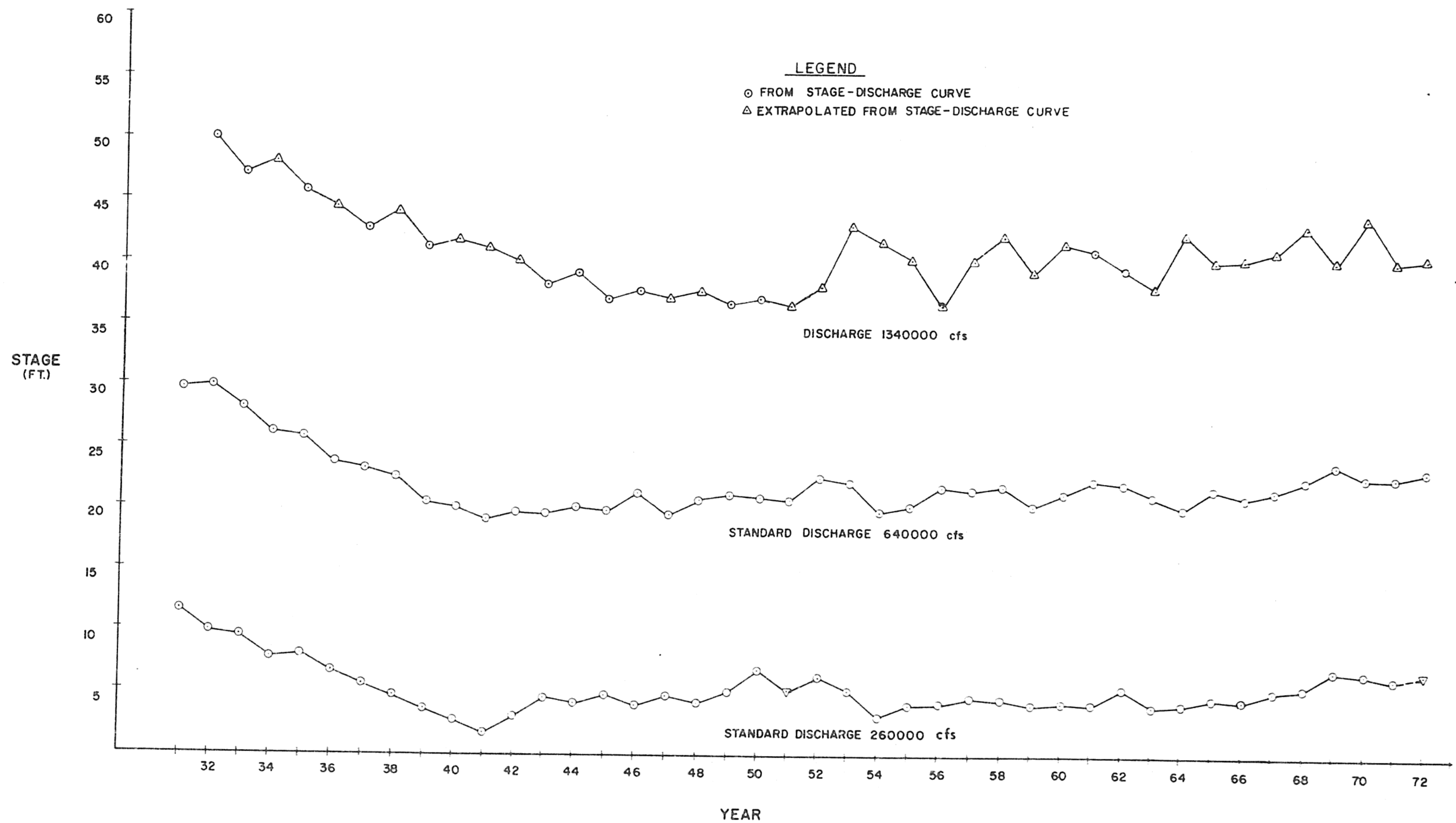

Figure 4.22 Estimated River Stage for Selected Flows in the Mississippi River at Vicksburg Between 1931 and 1972

St. Louis, Chester, and Thebes gages are all in the St. Louis Reach which has received most of the dike construction effort on the Mississippi River. Although average top-bank width appears to have decreased in response to dike construction activity by about 29 percent since 1908, the change in stage-discharge relations with time is different at each of the stations. In the Memphis Reach where dike construction activity has been only about 28 percent of that in the St. Louis Reach (in terms of length of dike per mile), changes in stage-discharge relations with time are similar to those observed at St. Louis but much more pronounced. In the Vicksburg Reach where dike construction was only about 18 percent of that in the St. Louis Reach (in terms of length of dike per mile), changes in stage-discharge relations with respect to time show an initial downtrend in stage for any given flow (less than 1,340,000 cfs) followed by an uptrend or rebound at about one-half the rate of the initial downtrend. Neither trend appears to be associated with dike construction activities in the reach.

The present analysis suggests that generalizations about effect of dikes on stage-discharge relations are not justified. It appears that other important, but so far unidentified, factors also influence stage-discharge relations. The Ohio River-Mississippi River responses near their confluence may be an example of mutual interference wherein modifications in one stream may cause a response in both. Because of the diversity in stage-discharge responses between stations, it appears that localized conditions may be the most important influence on these relations at individual stations. If this is so, then it is unlikely that an individual point of record is representative of conditions throughout a reach.

Whatever the reason, it appears that conveyance properties of the channel below flood stage have been increasing at the St. Louis and Memphis gages since about 1930. Channel conveyance at the Chester gage has remained unchanged over the period, 1943 through 1973. Conveyance properties at bankfull conditions appear to be decreasing at Thebes and Vicksburg gages. In the latter cases, the trend of decreased conveyance should be evaluated in terms of current and future protection afforded against flood hazard.